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A DEMONSTRATION TO RISK RATE STANDS TO DOUGLAS-FIR TUSSOCK MOTH DEFOLIATION on the Palouse Ranger District, Clearwater National Forest, Idaho

2. Predicting Defoliation Levels and
Evaluating Alternative Control Treatments

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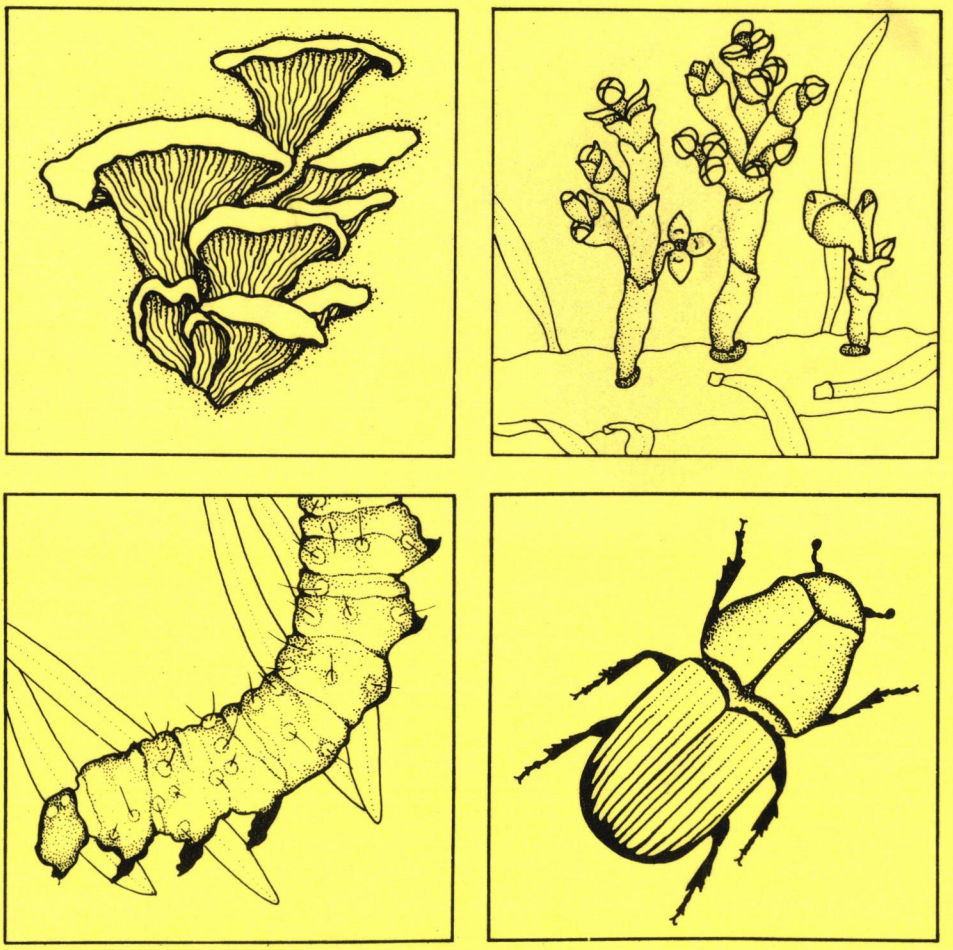

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A DEMONSTRATION TO RISK RATE STANDS TO DOUGLAS-FIR TUSSOCK MOTH DEFOLIATION ON THE PALOUSE RANGER DISTRICT: PART 2. PREDICTING DEFOLIATION LEVELS AND EVALUATING ALTERNATIVE CONTROL TREATMENTS[1]

by

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ABSTRACT

A two-stage study that demonstrates the combined use of Douglas-fir tussock moth (DFTM) risk-rating models and control treatment evaluation models developed under the auspices of the Expanded DFTM Research and Development Program is presented. In the first part of the study, forest stands on the Palouse Ranger District of the Clearwater National Forest with a greater than 60 percent probability of DFTM defoliation were rated as to their potential defoliation level using risk-rating models based on site and stand characteristics. Thirty-nine stands, encompassing some 1,440 acres, were risk rated.

In the second part of the study, the simulated effectiveness of insecticide controls, two thinning regimes, and a no-treatment alternative were evaluated in three stands: two immature stands currently of low defoliation risk, one composed of host and nonhost species, the other composed entirely of host species; and a mature stand composed predominantly of host species currently of high defoliation risk. The

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combined stand prognosis/DFTM outbreak model with economic and regeneration sub-routines was used to evaluate stand response to each treatment alternative in terms of volume yield, net present value, and defoliation risk. Control treatment efficiency was shown to change with stand types. The evaluation results indicated that thinning treatments favoring nonhost species, a combination of insecticide controls and thinning treatments favoring "less preferred" species, and "timely" harvests were the most efficient of the control treatments evaluated for the mixed species, host species, and mature host species stand, respectively. Management implications of the results are discussed.
This report presents the procedures needed for the application and use of DFTM risk-rating models and of models to evaluate alternative control treatments. In addition, this report quantifies the effects of forest and pest management activities on tussock moth impacts, thus portraying the potential benefits of integrated forest and pest management measures in long-term reduction of the tussock moth problem.

INTRODUCTION

The Douglas-fir tussock moth (Orgyia pseudotsugata McD.) is a native defoliator associated with Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) and true firs (Abies spp.) of western North America. Its outbreaks can cause substantial losses to timber and other values of the Douglas-fir and true fir forests of western North America (Beckwith 1978).

Models capable of risk rating stands to DFTM defoliation levels were developed to aid forest and pest managers in dealing with this pest. Our model, based on aerial photo interpretation techniques, was developed by Heller et al. (1977); Heller and Sader (1980) for forest conditions of the Blue Mountains of northeast Oregon and southeast Washington. Another model, based on ground inventory information of site and stand characteristics, was developed by Stoszek et al. (1981) for conditions of the Palouse Range of northern Idaho.

The model resulting from the latter efforts contained five site and stand variables: (1) the position of the stand on the slope, (2) the depth of the volcanic ash mantle at the site, (3) the average age of host trees, (4) the level of site occupancy (ratio of total tree density to site index), and (5) the percentage of grand fir in the stand (represented by a ratio of grand fir density to total density). Results of the aerial photo interpretation work were similar, but less detailed.

The biological interpretations derived from the risk-predictive variables suggest that tussock moth outbreaks develop in response to host foliage quality changes resulting from moisture and nutritional stresses. Sites with potential for moisture and nutrient deficiencies, or where standing biomass levels may have exceeded the carrying capacity of the site, appear prime candidates for heavy tussock moth defoliation (Stoszek et al. 1981).

The model variables and their interpretation seem to provide insights on the consequences of past forest and pest management activities, and are important in the design of future forest and pest management measures. Past fire suppression has favored the establishment and development of semi-tolerant and tolerant host tree species on climax sites for these species (Williams et al. 1980), resulting in overstocked, low-vigor stands. Selective logging has often had a similar effect, leaving residual stands composed of poor quality, low-vigor trees and encouraging the establishment and development of semi-tolerant and tolerant host species (Mika et al. 1981). Direct controls have been proven effective in reducing tussock moth populations and tree mortality (Mounts 1976), but may have maintained those site and stand conditions favoring tussock moth population buildups in the first place (Mika et al. 1981, Stoszek et al. 1981).

As for the implications on future forest and pest management, risk-rating systems aid the manager in predicting when, where, and to what

extent tussock moth defoliation will occur. The manager can use risk rating systems to identify high risk areas for the location of early detection, monitoring, and potential control efforts. There is also a potential for reducing future tussock moth damage through application of silvicultural practices that alter site and stand conditions associated with high tussock moth risk. When the risk-rating systems are linked with existing forest growth projection models, the combined system can be used for prediction of future impacts of tussock moth defoliation on forest stand composition, growth and yield, and for evaluation of the effectiveness of various control strategies.

In an attempt to implement the risk rating and impact-predicting systems that have been developed (Brookes et al. 1978), a two-stage pilot project was initiated by the USDA Forest Service Region 1, Cooperative Forestry and Pest Management, and the University of Idaho. The objective of the first stage was to rank forest stands on the Palouse Ranger District, Clearwater National Forest, as to their probability of defoliation. This task was accomplished by Kessler et al. (1981) to conditions on the Palouse Ranger District using data from work by Stoszek et al. (1977). This report describes the second stage of the project.

OBJECTIVES

Our first objective was to predict the intensity of tussock moth defoliation in those stands rated by Kessler et al. (1981) as having a greater than 60 percent probability of tussock moth defoliation. The second objective was to predict and compare (through the use of simulation models) the effectiveness of DFTM control treatments in terms of stand volume yield, net present value, and future defoliation risk. A parallel objective to the second one was the intent to demonstrate the use of simulation models.

METHODS AND PROCEDURES

Assessment of Stand Defoliation Risk

Forest stands ranked by Kessler et al. (1981) as having a moderately high to high probability (>60 percent) of defoliation were considered for prediction of tussock moth defoliation levels. The probable levels of tussock moth defoliation were predicted from a multivariable model developed from site and stand characteristics by Stoszek et al. (1981). The accessibility and size (>10 acres) of the forest stands were used as selection criteria.

Each stand was described from systematically located variable radius plots. The number of plots in each stand was based on the stand's photo interpretation (PI) class as follows: one plot per 5 acres in mature, multi-storied stands; one plot per 10 acres in mature, single-storied stands; and one plot per 15 acres in immature, single-storied stands.

The following information was obtained from each plot: total basal area, basal area in grand fir, heights of dominant and co-dominant host trees (Douglas-fir and grand fir), age at breast height for host trees, tree species, percent slope, slope position, and diameter at breast height (d.b.h.) of host species.

From these data the following predictive variables of the model predicting defoliation intensity (Stoszek et al. 1981) were derived:

(1) Slope position or physiographic location. Each stand was given a numerical ranking of 0 or 1 for lower and midslopes or upper slopes and ridgetops respectively. The slope position was obtained from topographic maps and verified from field data records.

(2) Average age of hosts. The age of host trees was determined from increment cores taken at breast height from three to eight host trees in each plot.

(3) Proportion of grand fir. The percent of grand fir basal area (BA) per plot was determined by dividing the BA in grand fir by the total BA of the plot.

(4) Depth of volcanic ash. The average depth of the ash cap was obtained from soil maps developed for the Palouse Ranger District.

(5) Site occupancy index. This term denotes a ratio of the stand's BA to the stand's Douglas-fir index (DFSI). Brickell's (1970) site curves and equations were used to calculate the DFSI. For plots lacking Douglas-fir site trees, grand fir trees were used to predict the DFSI using the following formula: DFSI = 43.77 + 0.4518 GFSI.

The predictive variables for each plot in a stand were summarized, averaged, and entered into the model predicting tussock moth defoliation levels (Table 1). Since the model predicts defoliation in logarithmic units, a first order bias correction, $\sigma\ 2/2 = .269378$, (Beauchamp and Olson 1973) was added to the model to obtain predictions in original units.

The defoliation predictions were grouped into four defoliation classes, as in Wickman (1978), and assigned the following color codings:

0.0 - 10.0%	green
10.1 - 25.0%	yellow
25.1 - 50.0%	orange
50.1 - 75.0%	red

Stand locations and defoliation class color codes were mapped on a topographic quadrangle map (Appendix A).

Table 1.--Predictive model for Douglas-fir tussock moth defoliation using basal area estimates (Stoszek et al. 1981).

Model: $\ln$ (% defoliation/host) = $b_0 + b_1 * SP + b_2 * AD + b_3 * \ln(HA) + b_4 * \ln(BA/SI) + b_5 * \ln(\%GF)$

where SP = slope position = 0 if lower slope
1 if upper slope

BA = total tree basal area (m^2/ha)

AD = depth of ash mantle (cm)

SI = Douglas-fir site index (m @ 50 years)

HA = age at breast height averaged over all host trees

%GF = 100 * Grand fir BA/Total BA

Parameter	Estimate	Standard deviation	Standardized coefficient	VIF
b_0	-0.681			
b_1	0.447	0.198	0.211	1.146
b_2	-0.012	0.005	-0.249	1.234
b_3	0.505	0.268	0.228	1.936
b_4	0.487	0.226	0.234	1.555
b_5	0.274	0.075	0.387	1.473

R^2 = 51.5% SEE = 0.734 = 32.5% of the mean

F = 13.60 P {F $\geq$ 13.60} < 0.0001

Demonstration stands.--Three stands differing from each other in management potential and characteristics associated with tussock moth defoliation risk were chosen for evaluation of alternative DFTM control treatments from those stands included in the pilot project. Two of the stands are sapling-sized stands that if left unattended would develop characteristics associatediated with high defoliation risk. One of these stands is composed of a mixture of host and nonhost species and the other is composed entirely of host species. The third stand, representing a high risk condition, is a mature stand composed predominantly of host species.

Treatments.--The simulated treatments encompassed three categories: (1) direct controls (one chemical insecticide and one polyhedral virus treatment regime); (2) silvicultural measures (two thinning regimes and one harvest-cut method in the young and mature forest stands, respectively), and (3) a no-treatment alternative to serve for comparison.

Each of the sapling-sized test stands were subjected to the two simulated control treatments, to two thinning regimes, and to the no-treatment alternative. One thinning regime was designed to reduce tussock moth defoliation risk by favoring the growth and development of nonhost or "less preferred" host species (Douglas-fir according to Stoszek et al. (1977, 1981)); the other thinning regime was designed to favor growth and development of host species (grand fir and Douglas-fir). The thinnings were applied in accordance with the silvicultural prescription guidelines for the Palouse Ranger District, Clearwater National Forest. The guidelines specify a reduction in stocking densities to a 10' x 10' spacing at a stand age of 20, a commercial thinning entry at 50 to 70 years of age aimed at a reduction of stocking densities to a crown competition factor (CCF) (Krajicek et al. 1961) of 100 to 125, and a final harvest at 100 years of age (Appendix B).

The direct controls consisted of aerial applications of chemical insecticide sprays and aerial applications of nuclear polyhedrosis virus. These controls were applied at the beginning of the peak phase of each outbreak episode. Under the no-treatment alternative, stands were grown without managerial interference, except for fire prevention, until harvest.

In the mature test stand, both the direct controls and the no-treatment alternative were applied. In place of the thinning treatments, two versions of a clearcut harvest-regeneration method were applied. One version employed prescribed burning for site preparation and relied on natural regeneration. The other version employed prescribed burning for site preparation, but resorted to planting of nonhost and "less preferred" host species.

Data collection.--A two-stage sampling scheme employing variable radius plots and 1/300-acre fixed plots was systematically located in the mature stand and 1/100 acre fixed radius plots were systematically located in the two sapling-sized stands. In addition to the data needed

for predicting data needed as inputs for the stand prognosis model (Stage 1973) were collected on each plot.

Evaluation procedures.--The consequences of each treatment on stand development and tussock moth impact were simulated and compared for each stand using an integrated computerized model composed of several separate models: the combined stand prognosis/DFTM outbreak model (Monserud 1978, Monserud and Crookston 1982); the computerized help for the economic analysis of prognosis model outputs (CHEAPO) developed by Medema and Hatch (1979); and the regeneration establishment model for the grand fir-cedar-hemlock ecosystem of the Northern Rocky Mountains (Ferguson et al. in review).

The combined model is composed of two separate models: the stand prognosis model and the DFTM outbreak model. The stand prognosis model (Stage 1973), an individual tree growth simulation model, was used to simulate growth and effects of silvicultural treatments for each demonstration stand. Stand data and volume yield were produced at 5-year intervals to rotation age. The stand data were used to predict the defoliation risk in each stand using the risk rating model (Stoszek et al. 1981) described earlier. The stand volume yields were used to assess the effectiveness of each demonstration treatment.

The DFTM outbreak model (Overton and Colbert 1976, 1978) was used to simulate the occurrence and impact of DFTM outbreaks through the projection period of each stand. The impact of the outbreaks were transferred to the stand prognosis model in the form of volume losses due to tree growth reduction, top kill, and mortality. In combination, the two models simulated stand growth and development as affected by silvicultural treatments, DFTM defoliation, and direct DFTM control treatments.

The combined model uses the Inland Empire version (3.3) of the prognosis model, and the DFTM outbreak model is calibrated for the Blue Mountains of northeast Oregon and southeast Washington. To insure that the outbreak model predicts outbreak intensities similar to those observed in the Palouse Range of northern Idaho, an attempt was made to recalibrate the model using data from the 1973 outbreak in the Palouse Range. Seven stands with known defoliation levels involved in the 1973 outbreak within the pilot project area, were run through the combined stand prognosis/ DFTM outbreak model. The initial outbreak conditions/--egg densities, egg allocation method, foliage biomass, and percent new foliage--were manipulated until the predicted defoliation levels approximated those observed in the field.

The following results of the recalibration attempt were used as initial outbreak simulation conditions in the demonstration stands: grand fir and Douglas-fir egg levels were 9, 7, 5 eggs/sample branch and 7, 6, 5 eggs/sample branch for each tree species, respectively. Each egg level was allocated to one-third of the diameter distribution of the host tree classes in descending order of size classes using method 3 described by

Monserud and Crookston (1982). This allocation method was used in an attempt to account for the tussock moth's preference for older grand fir trees in the Palouse Range (Stoszek et al. 1977, 1981). Foliage biomass and percent new foliage variables were assigned to each tree class using method 4 by Monserud and Crookston, ibid. Method 4 predicts biomass and percent foliage for each host tree class using formulas developed by Hatch and Mika (1978).

The probability of occurrence of a regional outbreak and the probability of the test stands being included in the outbreak were stochastically determined for the no-treatment alternative for each test stand following the procedures described by Monserud and Crookston (1982). The probability of a stand being included in a regional outbreak is conditional on the stand's probability to sustain an outbreak. This probability is based on site and stand conditions. Stand development, silvicultural treatments, DFTM defoliation, or any combination of these could alter the site and stand conditions and affect the probability of the stand's inclusion in a regional outbreak. In order to assess the consequences of each treatment alternative on an equal basis, the sequence of multiple outbreaks stochastically scheduled for the no-treatment alternative was deterministically scheduled for the other treatment alternatives for each of the demonstration stands using procedures described by Monserud and Crookston (1982). All other input variables needed to run the combined model were assigned in accordance with the procedures outlined by Monserud and Crookston (1982) (Appendix C).

The regeneration model for the grand fir-cedar-hemlock ecosystem (Ferguson et al. in review) was linked with the combined model to assess the consequences of various harvest, site preparation, and regeneration practices on new stand stocking levels and compositions. The newly regenerated stands were projected through a 100-year rotation under a no-treatment alternative using the combined model. The defoliation risks of the new stands were predicted from the simulation results using risk-rating models developed by Stoszek et al. (1981).

The computerized help for the economic analysis of prognosis model outputs model, CHEAPO, was linked to convert the volume yields output by the combined model and the economic information on the treatment alternatives into costs and benefits (revenues) and to discount these to present values. The net present value, discounted benefits minus discounted costs, provides a means for comparing the economic value of alternative treatments.

In order to use CHEAPO, economic assumptions (model inputs) had to be defined in accordance with the procedures outlined by Medema and Hatch (1979). Of the forest and pest management treatments simulated, insecticide applications, precommercial thinnings (removals with an average diameter greater than 4 inches, but less than 2.0 mbf in volume), annual administration, and annual protection expenses constituted costs, while revenues from commercial thinnings and harvest constituted benefits.

The revenues generated from commercial timber removals were determined from stumpage values for the following diameter size classes:

(1) Large sawtimber--trees with an average diameter greater than 16 inches.

(2) Small sawtimber--trees with an average diameter greater than 9 inches and valued at 60 percent of the larger sawtimber values.

(3) Pole timber--trees with an average diameter greater than 4 inches and valued at 60 percent of the small sawtimber values.

Costs were presumed to remain the same in real terms over the period of the simulations. However, stumpage prices were appreciated at a real rate of 3.0 percent annually, determined from previous economic studies of the historical annual increase in stumpage values (USDA For. Ser. 1973, Christophersen et al. 1978, Medema and Moore 1980). All costs and revenues were discounted at a real rate of 5 percent annually. This rate is used in other works dealing with Forest Service investments (USDA For. Ser. 1976, Clawson 1976). A summary of the actual values assigned to the aforementioned costs and benefits is shown in Table 2.

Table 2.--Economic assumptions for the CHEAPO subroutine.

Costs[1]	
Precommercial thinning	$91.00/acre
Noncommercial thinning	$91.00/acre
Forest protection	$ 0.50/acre/year
Administration	$ 2.00/acre/year
Chemical spray[2]	$ 7.00/acre
Virus spray[2]	$15.00/acre
Revenues[1]	
Large Sawtimber Stumpage Prices:	
White pine	$145.00/mbf
Western larch	$ 60.00/mbf
Douglas-fir	$ 60.00/mbf
Grand fir	$ 52.00/mbf
Western redcedar	$192.00/mbf
Lodgepole pine	$ 16.00/mbf
Ponderosa pine	$ 58.00/mbf
Other	
Stumpage value appreciation rate	3.00% annually
Discount rate	5.00% annually

[1]Costs and revenues obtained from Idaho Department of Lands, Coeur d'Alene, Idaho. 1980.

[2]Direct control costs obtained from USDA Forest Service Region 1. Forest Pest Management, State and Private. 1980.

RESULTS AND DISCUSSION

Assessment of Stand Defoliation Risk

The two-stage pilot project demonstrates how the technology developed to risk rate stands to DFTM defoliation can be used by land managers to predict where and to what extent defoliation is most likely to occur. In the first part of the pilot project, Kessler et al. (1981) used several photo interpretation techniques to predict the probability of DFTM defoliation in forest stands on the Palouse Ranger District. Using the ground survey risk rating techniques developed by Stoszek et al. (1977, 1981), those stands most likely to be defoliated (>60 percent probability) were rated as to their probable levels of DFTM defoliation. Thirty-nine stands, encompassing some 1,440 acres, were risk rated in this way. The risk rating model corrected for the logarithmic transformation bias predicted defoliation levels ranging from 10.07 to 51.90 percent average defoliation/host tree during phase II of an outbreak (Mason and Luck 1978). The corrected defoliation levels (Table 3) are approximately 30 percent higher than defoliation levels predicted without correction. Since the model predicts an average level of phase II defoliation for all host trees in a stand, it is best to use the predictions as comparative indices of a stand's risk status rather than equating the predicted levels with certain levels of expected impact.

Through integrated use of both risk rating models, stands where heavy levels of DFTM defoliation are most likely to occur were identified. Given this knowledge tussock moth population detection, monitoring, and control measures can be strategically applied. However, the decision of which kind of control measure to apply will depend on the type of stand being under potential DFTM threat and on the economic feasibility of each control alternative.

Evaluation of Tussock Moth Control Treatments

The second portion of this study demonstrates the use of simulation models for assessing each stand's situation relative to the effects of alternative control measures on volume yields, net present values, and tussock moth defoliation risks. This is illustrated in figures 1 through 6.

Mixed-species stand.--In the stand composed of a mixture of host and nonhost species (Table 4), thinnings favoring nonhost species appear effective in reducing DFTM damage and future defoliation risk. By discriminating against the host species, this thinning results in not only preventing development of stand conditions associated with high defoliation risk, but redistribution of the potential abiotic resources (light, moisture, and nutrients) to fewer, less susceptible, more valuable trees per acre. In addition, the thinning will capture the potential tree mortality. In response to these multiple effects, the thinnings favoring nonhost species produced the highest volume yield (78 mbf/A) and the highest net prevent value ($2,059/A) of any of the alternative control measures simulated. By reducing the host species component and biomass levels on the site, the thinning favoring nonhost species developed a stand with low defoliation risk (10.3 percent average phase II defoliation/host tree).

Table 3.--Site and stand characteristics and predicted defoliation levels.

Stand identification	Slope position	Host age (yr)	Percent grand fir	Ash depth (cm)	Site occupancy term (BA/DFSI)	Avg. phase II defoliation host tree (%)
44-4-18	1	81	35.4	44.45	1.724	19.37
52-1-2-1	1	70	73.3	0.0	0.913	27.47
52-1-2-2	1	68	87.5	0.0	0.989	29.55
52-1-5-1	1	69	43.4	43.18	2.402	22.54
52-1-5-2	1	115	52.6	0.0	2.428	51.90
52-1-5-4	1	76	26.8	13.06	1.424	23.08
52-1-9	1	85	18.1	37.78	1.794	18.24
52-1-13	0	72	50.0	30.48	0.743	10.07
52-1-14-2	1	81	58.9	37.47	2.382	28.34
52-2-2-1	1	72	0.0	0.0	1.336	10.34
52-2-2-3	1	70	8.4	0.0	1.273	17.84
52-2-4	1	65	24.2	0.0	1.010	20.52
52-2-8	1	63	66.7	0.0	0.903	25.25
52-2-9	0	114	62.5	30.48	2.644	25.05
5]-2-13-2	1	74	9.5	0.0	1.325	19.35
52-2-24	1	61	17.8	0.0	1.266	20.39
52-3-4	1	70	50.0	36.83	1.497	20.23
54-1-2	1	103	43.4	30.48	1.215	23.06
54-1-3	1	89	40.1	39.62	1.571	21.29
54-1-4	1	80	61.7	44.03	1.914	23.70
54-1-5-1	1	94	65.0	30.48	1.604	28.16
54-1-5-2	1	88	40.3	30.48	1.268	21.31
54-1-6	1	75	16.7	0.0	1.885	27.00

Table 3.--cont.

Stand identification	Slope position	Host age (yr)	Percent grand fir	Ash depth (cm)	Site occupancy term (BA/DFSI)	Avg. phase II defoliation host tree (%)
54-1-7	0	119	25.0	37.47	1.038	11.62
54-1-9	0	92	41.8	38.10	2.297	17.16
54-1-10	1	116	55.2	12.19	0.812	26.76
54-1-12	1	117	40.7	36.83	1.779	26.96
54-1-14	0	92	67.6	44.45	1.270	13.59
54-1-18	0	100	12.5	30.48	2.236	13.90
54-1-19	0	98	57.1	30.48	1.839	18.97
54-1-21-2	1	89	78.0	30.48	0.741	19.77
54-2-4	1	75	35.3	30.48	2.061	24.04
54-2-6	1	81	49.4	43.18	2.442	25.53
54-2-11	1	70	16.7	44.45	1.074	11.63
54-2-16	1	67	6.2	45.72	1.691	10.65
54-2-17	1	67	20.0	45.72	2.677	18.37
54-2-23	1	71	61.6	44.45	1.772	21.38
54-2-25	1	81	20.0	44.45	1.187	13.81
54-2-28	1	81	20.0	44.45	1.187	13.81

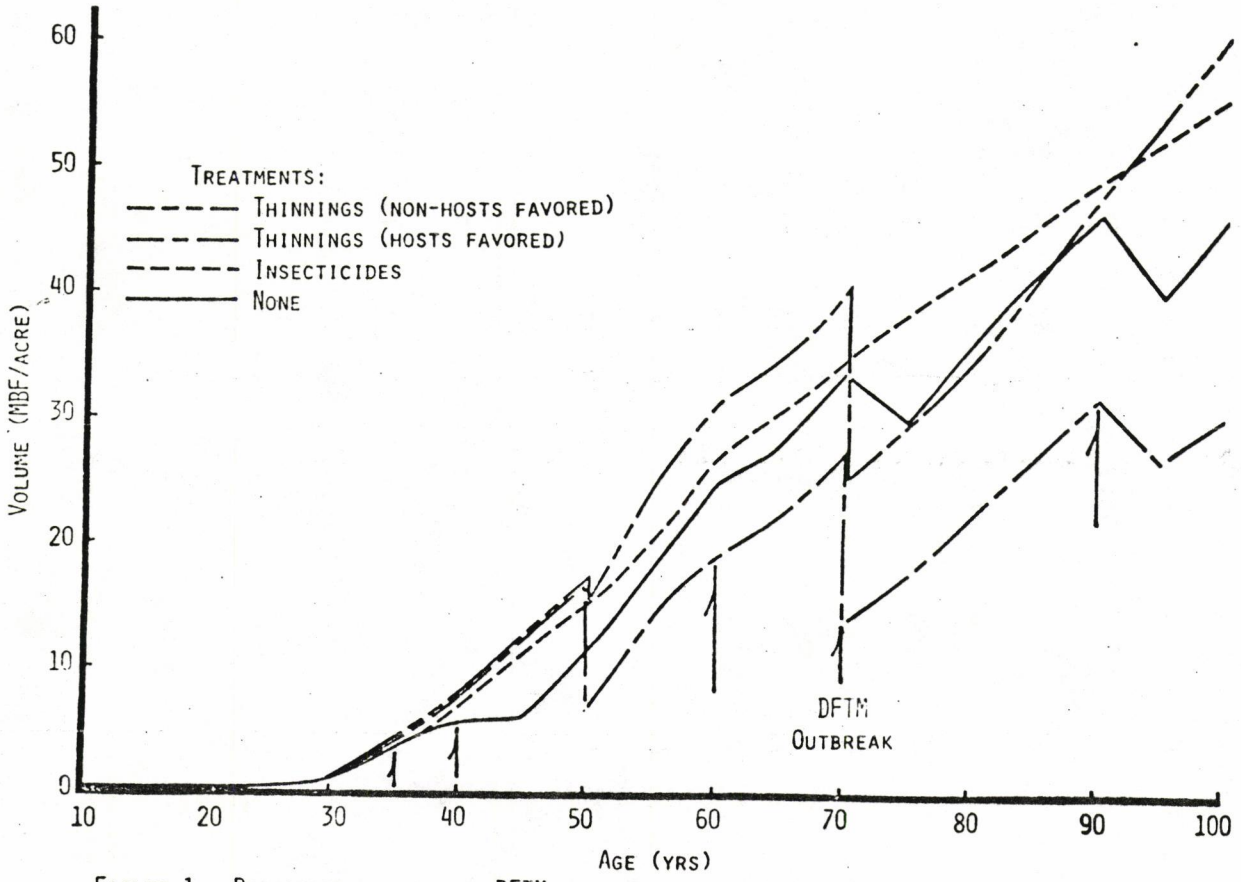

FIGURE 1. PREDICTED EFFECTS OF DFTM-CONTROL TREATMENTS ON STAND VOLUME YIELD: MIXED-SPECIES STAND.

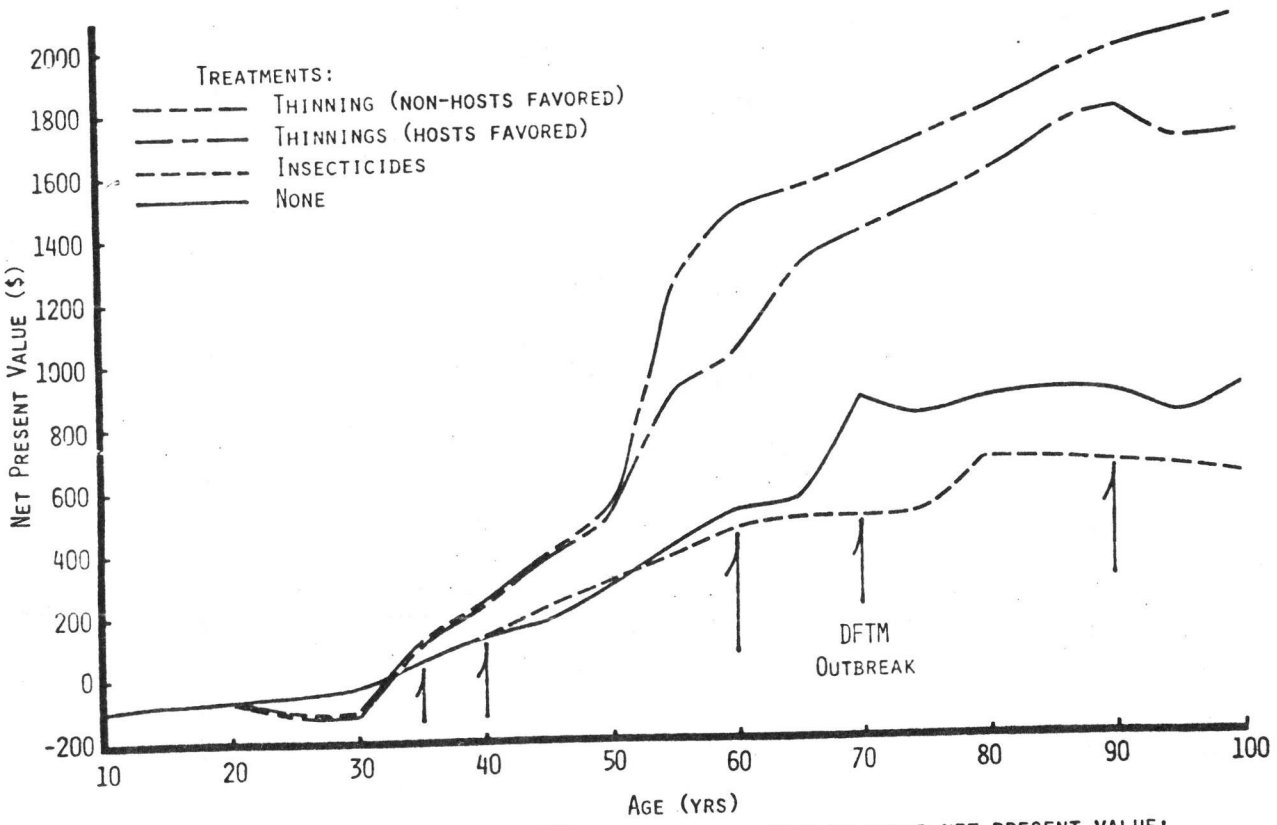

FIGURE 2. PREDICTED EFFECTS ON DFTM-CONTROL TREATMENTS ON STAND NET PRESENT VALUE: MIXED-SPECIES STAND.

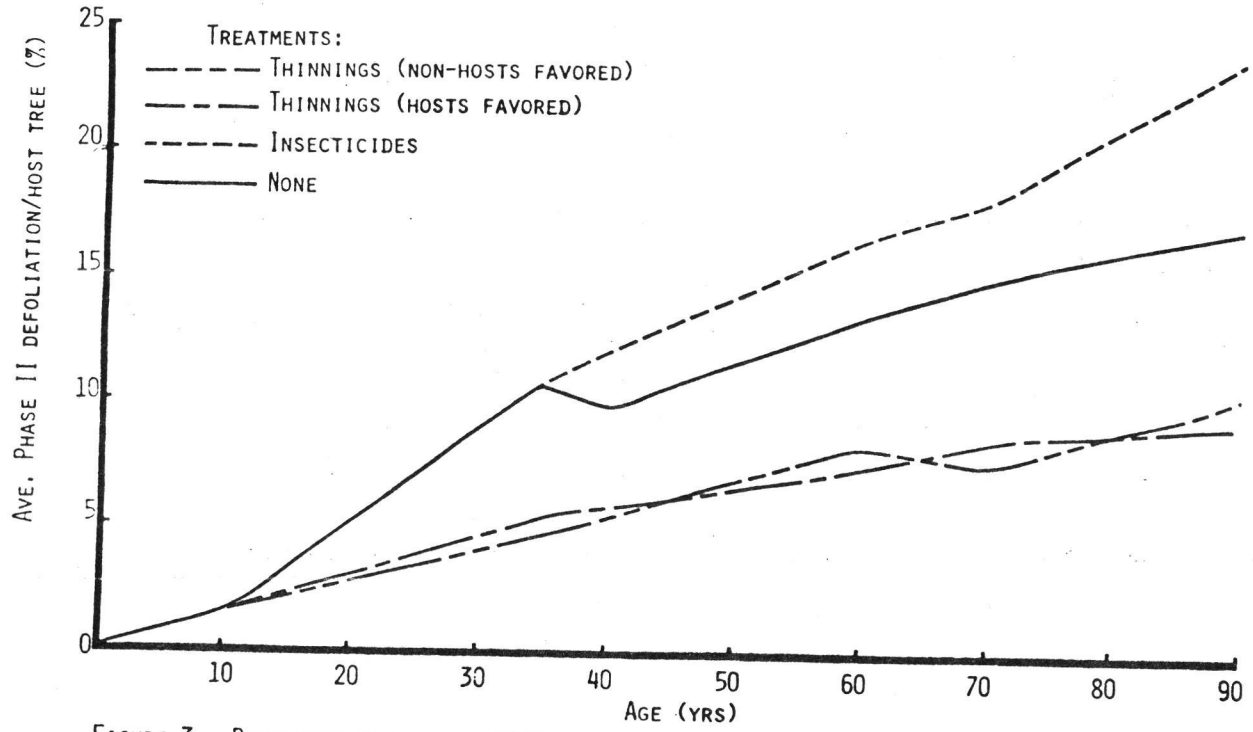

FIGURE 3. PREDICTED EFFECTS OF DFTM-CONTROL TREATMENTS ON STAND DEFOLIATION RISK: MIXED-SPECIES STAND.

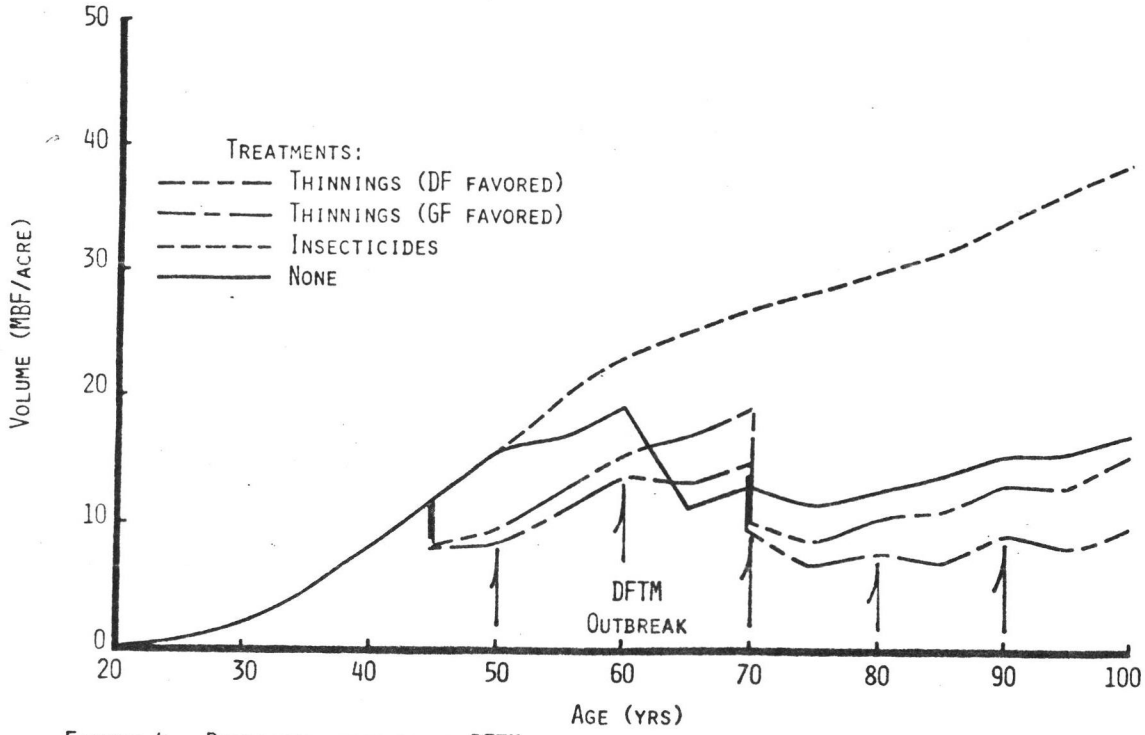

FIGURE 4. PREDICTED EFFECTS OF DFTM-CONTROL TREATMENTS ON STAND VOLUME YIELD: HOST-SPECIES STAND.

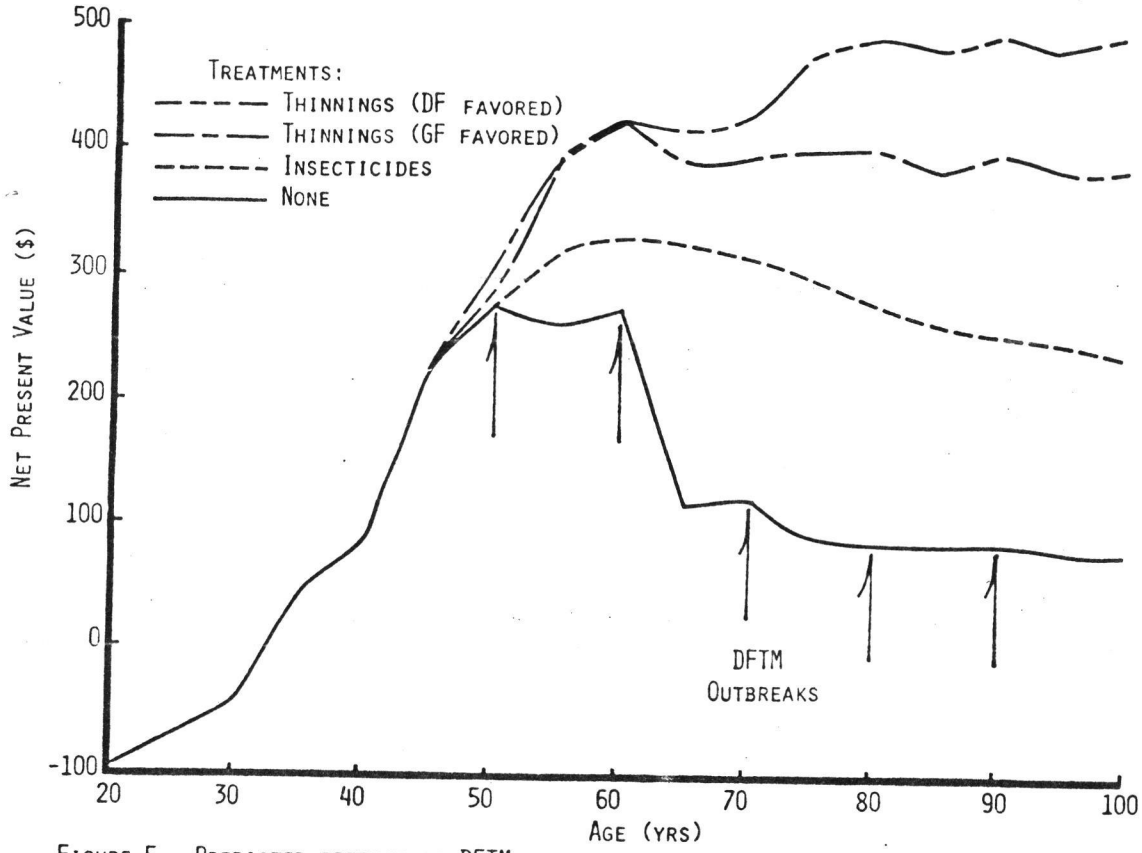

FIGURE 5. PREDICTED EFFECTS OF DFTM-CONTROL TREATMENTS ON STAND NET PRESENT VALUE: HOST-SPECIES STAND.

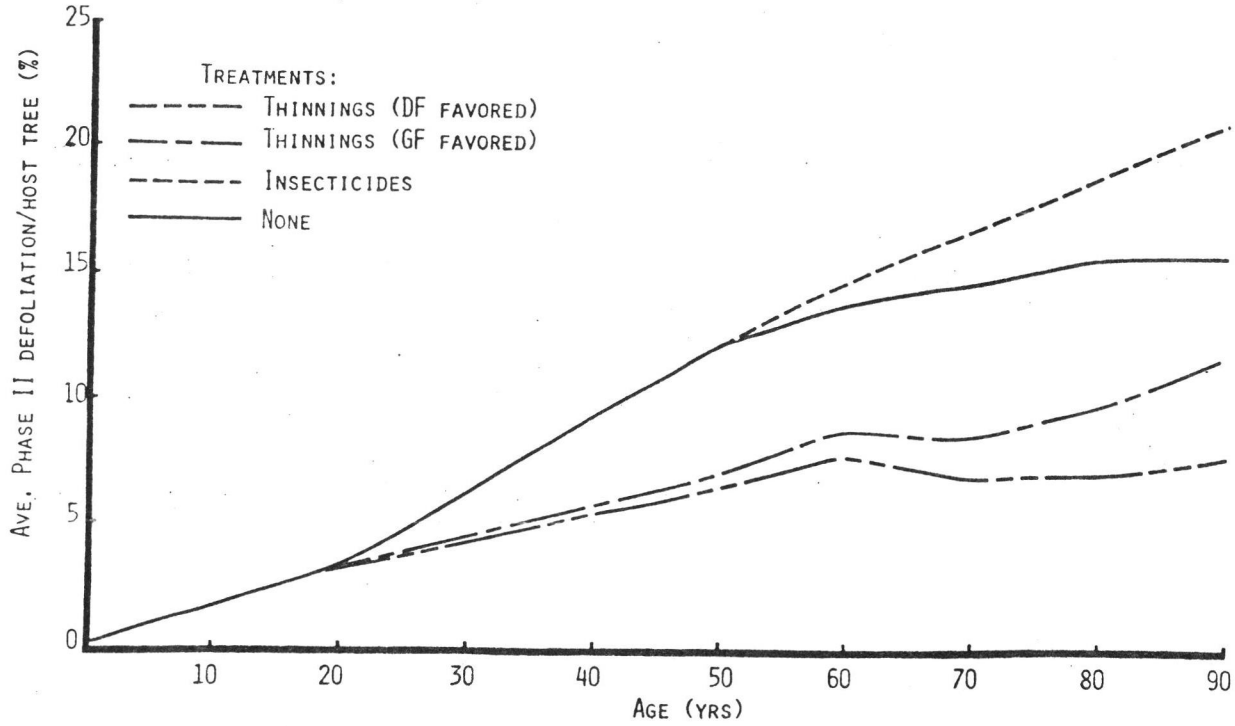

Figure 6. Predicted effects of DFTM-control treatments on stand defoliation risk: Host-species stand.

Table 4. Treatment effects on stand characteristics.

Mixed-Species Stand

	Site Conditions			Stand Conditions					
	Slope	Aspect	H.T.	Age	T/A	Composition	DBH	BA	CCF
Initial				10	2975	45%GF,39%DF,7%WRC,5%WP,4%WL&LLP	0.1		1
Thinnings (Non-Hosts Favored)				100	90	74%WP,23%DF,11%WL,2%WRC	22.6	250	150
Thinnings (Hosts Favored)	10%	NE	WRC/PACH	100	58	54%DF,40%WP,3%GF,2%WRC,1%WL&LLP	21.5	145	98
Insecticides				100	574	47%DF,38%GF,6%WP,5%WRC,3%WL&LLP	11.6	424	413
No Treatment				100	227	34%DF,21%GF,19%WP,15%WRC,11%WL	14.5	259	204

Host-Species Stand

	Site Conditions			Stand Conditions					
	Slope	Aspect	H.T.	Age	T/A	Composition	DBH	BA	CCF
Initial				20	767	70%DF,30%GF	2.8	32	49
Thinnings (DF Favored)				100	95	100%DF	14.6	110	99
Thinnings (GF Favored)	40%	NW	GF/PACH	100	99	78%DF,22%GF	12.0	78	79
Insecticides				100	291	73%DF,27%GF	13.5	288	262
No Treatment				100	127	72%DF,28%GF	13.5	126	116

Table 4 cont. Treatment effects on stand characteristics.

Mature Host-Species Stand

	Site Conditions			Stand Conditions					
	Slope	Aspect	H.T.	Age	T/A	Composition	DBH	BA	CCF
Initial				120	541	76%WRC,22%GF,1%DF,1%PP&WL	7.9	153	184
Post Harvest (Natural)	40%	NE	WRC/PACH	10	670	59%GF,19%DF,15%WRC,4%WL,3%LLP&ES	0.1		.2
Post Harvest (Planted)				10	881	56%GF,16%DF,11%WP,9%WRC,8%WL	0.1		.2

The alternative thinning regime, which discriminated against nonhost species, developed a stand with a higher proportion of high-risk host species and fewer high-valued nonhost species than the thinnings favoring nonhost species (Table 4). As a result, the alternative thinning treatments only produced a volume yield of 53.4 mbf/A with a rotation net present value of $1,696/A. The larger biomass reduction on this site, due to defoliation-induced mortality of the host species, accounts for this treatment alternative having a lower defoliation risk (9.3 percent average phase II defoliation/host tree) than the thinning treatments favoring nonhost species.

In agreement with the findings of Mounts (1976), the insecticide treatments were effective in reducing tussock moth populations and saving timber inventories. The chemical insecticides produced slightly better results than the nuclear polyhedrosis virus because of lower application costs and higher effectiveness. Although proven effective, the insecticide treatments helped to develop a stand with high-risk characteristics, e.g., high biomass levels and predominantly highly susceptible grand fir (Table 4). As a result, the insecticide treatments produced a volume yield of 55.5 mbf/A with a net present value of only $615/A and a stand with the highest defoliation risk (23.9 percent average phase II defoliation/host tree) of any of the alternative treatments.

Under the no-treatment alternative, the tussock moth was allowed to exert its natural role as regulator of primary forest production (Mattson and Addy 1975). The tussock moth outbreaks reduced the biomass levels on the site through defoliation-induced mortality of the host species, resulting in the lowest volume yield (45.9 mbf/A) of any of the alternative treatments. However, this defoliation-induced mortality of the host species also released the more valuable nonhost species, resulting in a higher net present value ($888/A) and lower defoliation risk (11.6 percent average phase II defoliation/host tree) than the insecticide treatment. This "thinning" effect exerted by the defoliation was correlated with computer simulations of DFTM outbreaks in juvenile ponderosa pine (Pinus ponderosa) Laws.)/Douglas-fir/grand fir stands by Moore and Hatch (1981).

Host species stand.--In the stand composed entirely of host species (Table 4), the application of thinning treatments favoring nonhost species was limited to discriminating against grand fir, the preferred host, over the "less preferred" Douglas-fir. For this reason, these thinning treatments were not as effective as in the mixed-species stand. These thinnings and the defoliation-induced mortality lowered biomass levels on the site. As a result, the potential growth energy of the site was redistributed to the "less preferred" and more valuable Douglas-fir component of the stand. This produced the stand's highest net present value ($490/A) and the second highest volume yield (30.4 mbf/A). The lower biomass levels and the reduced grand fir component of the stand under this treatment alternative produced the lowest future defoliation risk (7.8 percent average phase II defoliation/host tree).

The results generated by the thinning regime favoring Douglas-fir are considerably better than those of the alternative thinning treatments. By discriminating against Douglas-fir, the "less preferred" host, these thinnings developed a stand with a large component of less valuable grand fir that is more susceptible to defoliation (Table 4). This high-risk stand composition lead to an increase in defoliation-induced mortality, which lowered both the volume yield produced (21.4 mbf/A) and the net present value ($387/A), while it increased the defoliation risk (11.6 percent average phase II defoliation/host tree).

The insecticide treatments were shown to be more effective in the host-species stand where stand composition hindered the application and effectiveness of thinning treatments favoring nonhost species. By reducing the tussock moth population and saving the timber inventory, the insecticide treatments produced the largest volume yield (38.6 mbf/A) of any of the treatment alternatives. However, besides adding a cost burden, the insecticide treatments also increased the proportion of less valuable grand fir in the stand and allowed high biomass levels to develop on the site (Table 4). As a result, the insecticide treatments produced a lower net present value ($234/A) than the thinning treatments and the highest defoliation risk (21 percent average phase II defoliation/host tree). These results support Stoszek's et al. (1977, 1981) contention that in the long run, insecticide treatments increase stand susceptibility to tussock moth defoliation.

Under the no-treatment alternative, the stand's composition dominated by host species precluded development of the defoliation-caused "thinning effect" observed in the mixed-species stand situation. As a result, the no-treatment alternative produced the lowest volume yield (16.7 mbf/A) and the lowest net present value ($77/A) among the alternative treatments. Under the no-treatment alternative, the stand produced a higher biomass level and a larger proportion of grand fir than if subjected to the thinning treatments (Table 4). This resulted in the second highest defoliation risk (15.6 percent average phase II defoliation/host tree).

Mature host-species stand.--In the case of mature host-dominated stands, or high-risk site configurations, the manager facing an impending DFTM outbreak needs to know the cost-benefits associated with (1) an immediate (preoutbreak) harvest cut, (2) application of associated controls, and (3) a do-nothing alternative. Our simulation results show that by projecting the mature stand through one tussock moth outbreak under the no-treatment alternative, the stand's net present value was lowered from $1,120/A at the time of inventory to $1,006/A following the outbreak. Insecticide treatments raised the stand's postoutbreak net present value to $1,061/A. This indicated that to maximize financial returns, the stand should be harvested prior to defoliation.

The harvest-regeneration simulations resulted in two new stands of similar composition (Table 4). Without management interventions, the predicted defoliation risk of the naturally and artifically regenerated stands would be 23.0 percent and 24.7 percent average phase II defoliation/host tree, respectively. However, the simulation results suggest that either of the two harvest regeneration systems would establish new stands with species compositions amenable to applications of thinning treatments favoring nonhost species.

Management Implications

The simulation results indicate that in mixed-species stands, thinning treatments favoring nonhost species and the no-treatment alternative are potentially best suited to reduce the risk and damage to DFTM defoliations. The thinning treatments are applicable in commercial mixed-species stands; while the no-treatment alternative provides a viable management option in economically or technically inoperable mixed-species stands.

In host-species stands, the simulation shows the use of insecticide treatments (either chemical or biological virus depending on economic and environmental constraints) is warranted for short-term control of the tussock moth. However, these treatments should be followed or used in conjunction with thinning treatments favoring the "less preferred" species to facilitate long-term reduction of tussock moth defoliation risk. The results also indicate that to optimize financial returns from host-species stands, the stands should be harvested at an age corresponding with the peak of the net present value curve for each stand and treatment strategy.

The simulation results indicate that in mature host-species stands on high-risk sites, timely harvest is needed to reduce present high defoliation risk and maximize financial returns. The simulation models also proved useful in assessing the effects of harvest-regeneration methods on the species composition of future stands and the amenability of these stands to tussock moth risk-reducing silvicultural practices.

There is a need to mention that the combined model (Monserud and Crookston 1982) used for evaluating the demonstration treatments does not account for the effects of treatment-changed stand characteristics on defoliation levels. The model only alters the stand's defoliation probability in relation to treatment-induced changes in stand characteristics and predicts a relatively constant level of defoliation through time. This defoliation level is set by the initital outbreak conditions, i.e., percent new foliage and egg density. The unresponsiveness of the combined model to natural or treatment-induced changes in stand conditions is portrayed in Figure 7, in which the defoliation levels predicted by the combined model are compared to defoliation levels reflecting natural and treatment-induced changes in stand characteristics predicted by the defoliation risk-rating model developed by Stoszek et al. (1981). If the combined model could be modified to account for the effects of treatment-changed stand characteristics on defoliation levels, additional gains in treatment effectiveness would possibly be demonstrated.

To ascertain whether the differences between treatment efficiencies were due to either the level of tussock moth defoliation or the differential growth rates between tree species, the two thinning regimes in stands composed of host-species were simulated and compared with and without tussock moth defoliation. The thinning regime favoring Douglas-fir produced a volume yield of 31.9 mbf/A with defoliation and 44.7 mbf/A without defoliation. Both thinning regimes produced similar volume yields without defoliation. This suggests that the difference between the two thinning regimes with defoliation (8.1 mbf/A) is due primarily to different levels of defoliation under each thinning regime.

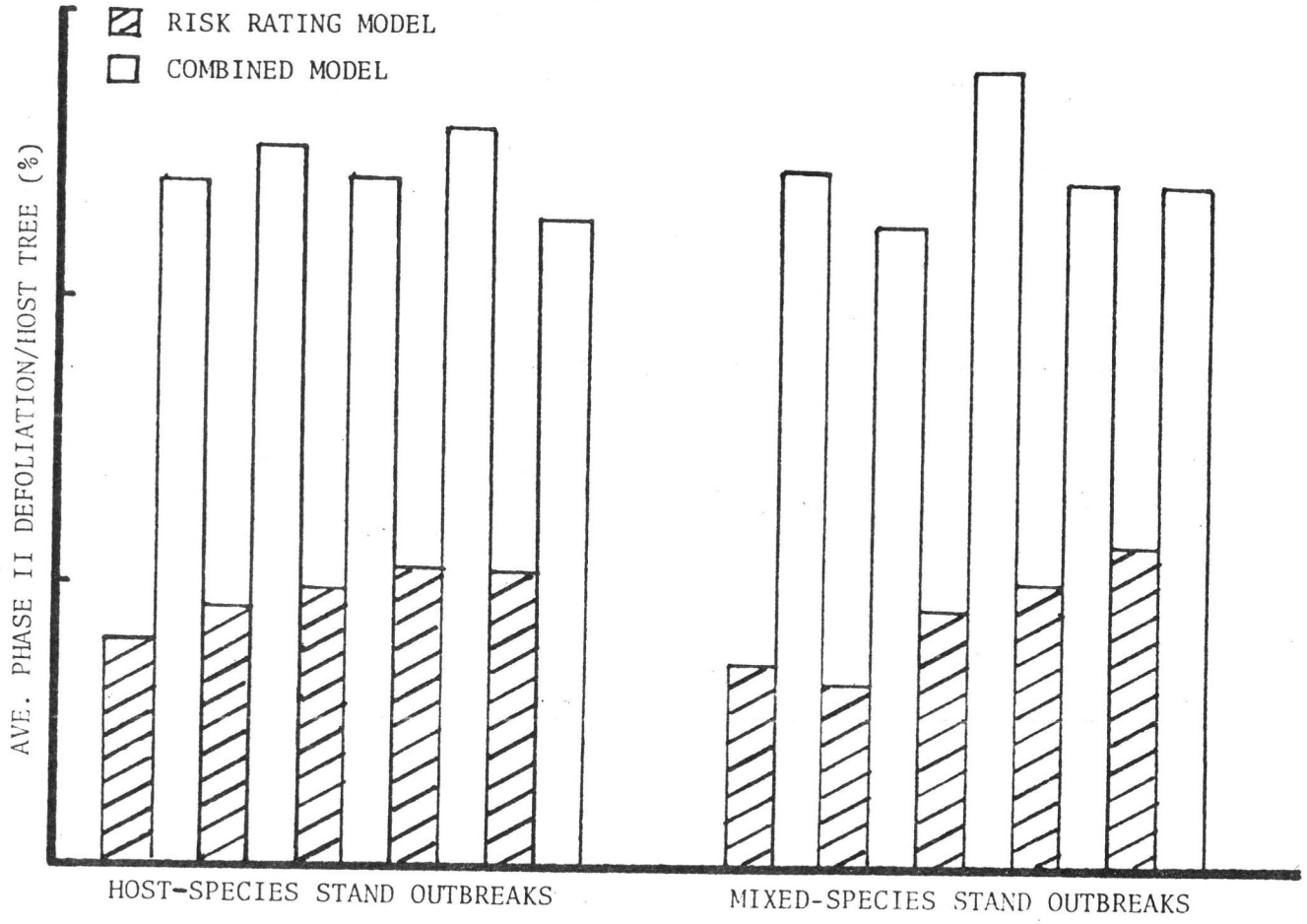

Figure 7. A comparison of successive DFTM outbreak defoliation levels predicted by the combined model (Monserud and Crookston 1982) and the risk rating model (Stoszek et al. 1981).

As is apparent from the simulation results, the efficiency of silvicultural and insecticidal controls changes with the stand's species composition. Based on this observation, stands with a high-risk potential could be grouped into treatment-suitability categories. Such grouping would facilitate development of treatment blocks in the field and provide an opportunity for integration of forest and pest management planning.

The simulation results also show that the decision to apply an insecticide treatment, or do nothing, is essentially a silvicultural decision as it affects, in presence of an outbreak, the competitive relationships among trees and consequently volume and value production. As such, the design of pest management strategies and measures should follow the steps appropriate for design of silvicultural prescriptions.

As a final note, the reader should bear in mind that the results presented are products of models developed under certain sets of environmental conditions, tussock moth population levels, and economic assumptions. Thus, use of these models outside the range without reparameterization could lead to misleading results; Gregg and Twardus (1981) have outlined such a reparameterization procedure.

Despite the limited validity of obtained results in absolute terms, the conceptual observations derived are, we think, applicable beyond the realms of conditions represented in the Palouse Range of Idaho.

CONCLUSION

The first part of the pilot project demonstrates the use of aerial and ground survey based DFTM risk models to delineate stands by outbreak probability and defoliation severity criteria. Delineation of stands into risk categories should increase the efficiency of pest detection efforts, design of pest control strategies, and aid in preparation of short- and long-term forest management plans. In addition, the first part of the pilot project establishes a case study area to test/validate the tussock moth risk-rating models during future DFTM outbreaks.

The second part of the pilot project demonstrates that evaluation of alternative tussock moth control measures is possible through the use of the combined Stand Prognosis/DFTM Outbreak model linked with economic and regeneration subroutines. The evaluation results indicate that treatment efficiency changes with stand type. The results obtained for each of the three test stands suggest that:

- In immature mixed-species stands, thinning treatments favoring nonhost species are potentially best capable of providing long-term control of the tussock moth. In inoperable mixed-species stands, the no-treatment alternative is also a viable management option.

- In immature host-species stands, a combination of insecticide controls and of thinning regimes that favor the less-preferred host species should be used to facilitate both short- and long-term control of the tussock moth.

. In mature, predominantly host-species stands, timely harvests should be initiated to reduce immediate risk and maximize financial returns.

With these insights, stands with high risk potential can be classified and grouped by treatment efficiency-type needs. Thus, identified treatments can then be used to integrate forest and pest management strategies, by designing silvicultural prescriptions for intermediate cultural practices and scheduling harvest-regeneration cuts.

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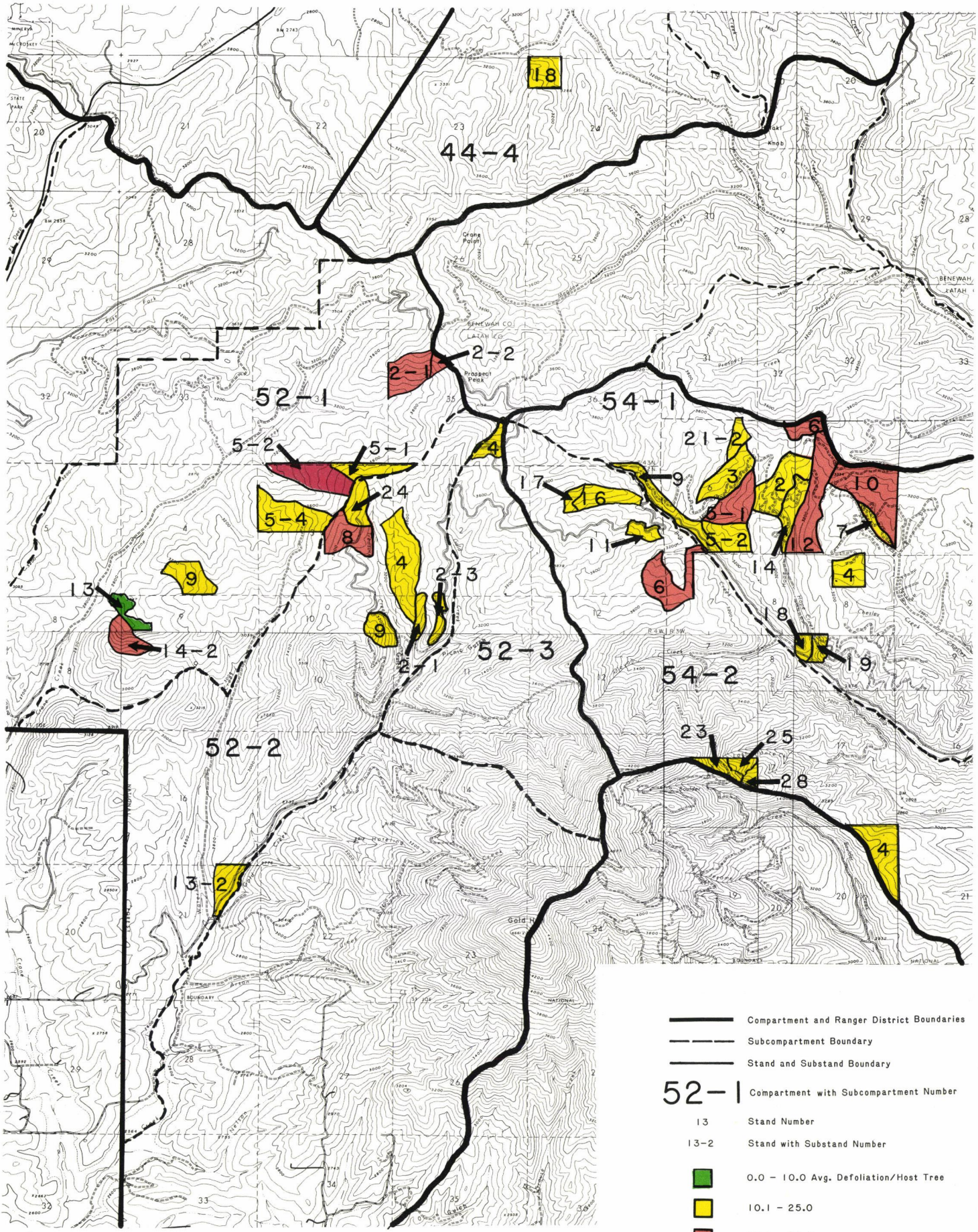
Appendix A. Color-coded stand map of DFTM defoliation classes.



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Appendix B. Summary tables of the simulated thinning regimes.

Appendix B. Summary tables of the simulated thinning regimes.

Mixed Species Stand: Non-Hosts Favored

9999-SUMMARY TABLE						AVE DOM	VOLUME PER ACRE			REMOVALS PER ACRE				GROWTH		
YEAR	AGE	TREES /ACRE	BA/ ACRE SQFT	CCF		HT FT	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	FRO YRS	ACC CUFT/YR	MOR
1980	10	2975	0	1		4	3	0	0	0	0	0	0	5	36	0
1985	15	2900	18	42		18	182	0	0	0	0	0	0	5	158	1
1990	20	2829	33	80		31	1017	26	0	2397	587	0	0	5	95	8
1995	25	398	58	75		36	872	425	252	0	0	0	0	5	135	12
2000	30	368	86	101		45	1491	1095	1133	0	0	0	0	5	191	15
2005	35	345	123	129		54	2369	1996	4240	0	0	0	0	5	177	36
2010	40	323	144	141		63	3073	2679	7808	0	0	0	0	5	213	49
2015	45	284	167	155		70	3936	3481	12506	0	0	0	0	5	169	27
2020	50	273	148	129		76	4747	4208	16823	68	781	892	2251	5	409	35
2025	55	195	197	155		84	5833	5173	24206	0	0	0	0	5	329	50
2030	60	187	224	168		91	7230	6375	31357	0	0	0	0	5	225	140
2035	65	156	219	153		98	7709	6762	34599	0	0	0	0	5	261	57
2040	70	150	157	119		93	8731	7639	40162	33	3230	2790	15389	5	313	49
2045	75	109	169	114		97	6318	5565	29181	0	0	0	0	5	232	40
2050	80	108	164	121		102	7280	6405	34189	0	0	0	0	5	274	54
2055	85	102	205	130		113	8628	7557	41051	0	0	0	0	5	344	67
2060	90	98	223	139		119	10014	8700	47879	0	0	0	0	5	304	80
2065	95	93	236	144		126	11138	9629	53715	0	0	0	0	5	346	86
2070	100	90	250	150		133	12426	10698	60571	0	0	0	0	0	0	0

Mixed Species Stand: Hosts Favored

9999-SUMMARY TABLE						AVE DOM	VOLUME PER ACRE			REMOVALS PER ACRE				GROWTH		
YEAR	AGE	TREES /ACRE	BA/ ACRE SQFT	CCF		HT FT	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	FRO YRS	ACC CUFT/YR	MOR
1980	10	2975	0	1		4	3	0	0	0	0	0	0	5	38	0
1985	15	2900	18	42		18	182	0	0	0	0	0	0	5	148	1
1990	20	2829	33	80		31	1017	26	0	2397	600	0	0	5	94	6
1995	25	393	57	75		36	868	425	253	0	0	0	0	5	132	11
2000	30	368	86	101		45	1443	1085	1135	0	0	0	0	5	189	15
2005	35	345	122	129		55	2336	1973	4254	0	0	0	0	5	175	27
2010	40	315	144	143		63	3078	2684	7790	0	0	0	0	5	210	56
2015	45	274	162	151		70	3830	3406	12382	0	0	0	0	5	188	26
2020	50	264	145	105		61	4662	4134	16639	59	2306	2050	10163	5	303	17
2025	55	196	153	144		69	3785	3370	14186	0	0	0	0	5	204	25
2030	60	190	175	157		74	4684	4179	18908	0	0	0	0	5	173	71
2035	65	169	161	136		79	5177	4644	23026	0	0	0	0	5	231	37
2040	70	163	123	112		78	6163	5522	27177	46	2819	2514	13183	5	172	61
2045	75	102	131	111		86	3901	3515	17284	0	0	0	0	5	202	23
2050	80	99	151	122		94	4735	4339	22004	0	0	0	0	5	211	29
2055	85	96	148	131		101	5736	5111	26560	0	0	0	0	5	228	36
2060	90	93	184	139		108	6665	5942	31599	0	0	0	0	5	113	388
2065	95	57	136	93		113	5548	4870	26611	0	0	0	0	5	161	30
2070	100	58	145	98		119	6203	5433	32033	0	0	0	0	0	0	0

Appendix B cont. Summary tables of the simulated thinning regimes.

Host Species Stand: DF Favored

9999-SUMMARY TABLE						VOLUME PER ACRE			REMOVALS PER ACRE				GROWTH		
YEAR	AGE	TREES /ACRE	BA/ ACRE SQFT	CCF	AVE DOM HT FT	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	PRD YRS	ACC CUFT/YR	MOR
1980	20	767	32	49	30	328	170	0	0	0	0	0	5	80	4
1985	25	680	56	77	39	706	510	572	0	0	0	0	5	93	5
1990	30	623	78	101	46	1144	926	1676	0	0	0	0	5	151	9
1995	35	564	114	142	47	1854	1566	4361	0	0	0	0	5	162	13
2000	40	524	144	171	54	2598	2212	7789	0	0	0	0	5	184	21
2005	45	490	110	130	54	3411	2939	11787	167	1363	1251	5683	5	140	13
2010	50	307	133	150	59	2682	2237	9137	0	0	0	0	5	151	46
2015	55	261	147	154	64	3206	2745	12153	0	0	0	0	5	150	22
2020	60	250	166	167	69	3845	3337	15300	0	0	0	0	5	127	103
2025	65	208	162	157	73	3967	3495	16409	0	0	0	0	5	124	25
2030	70	201	105	107	72	4464	4023	18995	34	1854	1787	9215	5	45	116
2035	75	136	87	88	75	2254	1946	8298	0	0	0	0	5	99	12
2040	80	132	99	97	79	2488	2394	10241	0	0	0	0	5	80	91
2045	85	111	93	89	82	2633	2381	10556	0	0	0	0	5	109	14
2050	90	108	106	92	87	3104	2887	13118	0	0	0	0	5	50	85
2055	95	97	98	91	79	2932	2723	12672	0	0	0	0	5	112	16
2060	100	95	110	98	84	3412	3197	15461	0	0	0	0	0	0	0

Host Species Stand: GF Favored

9999-SUMMARY TABLE						VOLUME PER ACRE			REMOVALS PER ACRE				GROWTH		
YEAR	AGE	TREES /ACRE	BA/ ACRE SQFT	CCF	AVE DOM HT FT	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	TREES /ACRE	TOTAL CU FT	MERCH CU FT	SCRIB BD FT	PRD YRS	ACC CUFT/YR	MOR
1980	20	767	32	49	30	328	170	0	0	0	0	0	5	80	4
1985	25	680	56	77	39	706	510	572	0	0	0	0	5	93	5
1990	30	623	78	101	46	1144	926	1676	0	0	0	0	5	151	9
1995	35	564	114	142	47	1854	1566	4361	0	0	0	0	5	162	13
2000	40	524	144	171	54	2598	2212	7789	0	0	0	0	5	184	21
2005	45	490	100	121	54	3411	2939	11787	86	1575	1449	6478	5	132	12
2010	50	382	123	142	59	2441	2005	8126	0	0	0	0	5	127	42
2015	55	331	134	145	64	2867	2408	10517	0	0	0	0	5	151	20
2020	60	315	154	160	68	3523	3003	13640	0	0	0	0	5	121	182
2025	65	244	134	134	73	3218	2748	12755	0	0	0	0	5	111	19
2030	70	236	105	109	73	3679	3231	14703	20	1115	1068	5493	5	52	200
2035	75	159	72	76	76	1822	1554	6440	0	0	0	0	5	81	10
2040	80	154	83	85	80	2182	1909	7657	0	0	0	0	5	44	94
2045	85	132	72	75	83	1933	1699	6468	0	0	0	0	5	95	10
2050	90	128	84	85	87	2354	2153	8997	0	0	0	0	5	48	116
2055	95	101	70	71	90	2013	1839	7718	0	0	0	0	5	73	10
2060	100	99	78	79	93	2328	2126	9435	0	0	0	0	0	0	0

Appendix C. Example of DFTM outbreak model inputs: insecticide treatment of the host species stand.

Appendix C. Example of DFTM outbreak model inputs: insecticide treatment of the host species stand.

INSECT MODELS: DOUGLAS-FIR TUSSOCK MOTH IN DOUGLAS-FIR AND GRAND FIR VERSION 1.3 / V3.3(NI)

STAND ID= 44-3-4 ; MANAGEMENT ID= NONE

DFTM OPTIONS AND INPUT TABLE

KEYWORD	** = KEYWORD SPECIFIED	KEYWORD DISCRIPTION AND PARAMETER VALUES USED
MANSCHED	**	REGIONAL OUTBREAKS SCHEDULED BY USER.

CYCLE NUMBER	CYCLE YEAR	TUSSOCK MOTH YEAR
7	2010	2010
9	2020	2020
11	2030	2030
13	2040	2040
15	2050	2050

MANSTART	**	STAND IS INCLUDED IN ALL REGIONAL OUTBREAKS.
PROBMETH		CONDITIONAL PROBABILITY OF STAND BEING INCLUDED IN A REGIONAL OUBREAK IS A FUNCTION OF: ELEV, SLOPE, ASPECT, TOPO, CROWN CLOSURE, CROWN WIDTH, AND %HOST (METHOD 1) PROBABILITY SCALING FACTOR = 1.000
TOPO		TOPOGRAPHIC POSITION CODE = 1.00; 1=RIDGETOP,2=SIDEHILL,3=BOTTOM.
ASHDEPTH		SOIL ASH DEPTH IN INCHES = 15.930
		EGG ALLOCATION BY THIRDS OF AVERAGE DBH DISTRIBUTION (METHOD 3)
DFEGGS	**	THREE LEVELS OF EGGS ON DOUGLAS-FIR NOMINAL BRANCHES: 7.0 6.0 5.0
GFEGGS	**	THREE LEVELS OF EGGS ON GRAND FIR NOMINAL BRANCHES: 9.0 7.0 5.0
BIOMASS		ASSIGNMENT USING BASAL AREA PERCENTILE AND SPECIES, WITH ADDITIVE RANDOM VARIATION (METHOD 4)
NUMCLASS		NUMBER OF REQUESTED CLASSES OF DOUGLAS-FIR= 20; GRAND FIR= 20 PROPORTION OF CLASSES DEFINED BY FINDING DIFFERENCES BETWEEN TREES = 0.50 THE REMAINING CLASSES ARE FOUND BY HALVING THE CLASSES WITH THE MOST TREE RECORDS.
WEIGHT		THE CLASSIFICATION WEIGHTING FACTORS ARE: 2.00 FOR % NEW FOLIAGE, AND 1.00 FOR FOLIAGE BIOMASS.
REDIST		ANNUAL INSECT REDISTRIBUTION RATE = 0.25
CC2E95	**	OUTBREAK MODEL PARAMETER VALUES: 0.2437